Semiannual Progress Report No. 7

A STUDY OF SELECTED RADIATION AND PROPAGATION PROBLEMS RELATED TO ANTENNAS AND PROBES IN MAGNETO-IONIC MEDIA

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1. INTRODUCTION

This semiannual report covers the activities in the period from 31 March, 1966 to 1 October, 1966. A few of the research subjects have been terminated and some new ones introduced.

2. SUMMARY OF THE RESEARCH

2.1. Impedance of an Electric Current Loop in an Anisotropic Cold Plasma. Theory and Experimental Verification - G. L. Duff

During the summer, G. L. Duff completed his Ph.D. Thesis on the above subject. This work will be published shortly as a Scientific report.

2.2. Current Distribution and Input Admittance of a Cylindrical Antenna in Anisotropic Plasma. - Y. T. Lo, S. W. Lee

The work on infinite cylindric antenna in a magneto-plasma is concluded. A paper which summarizes this work has been accepted for publication in the IEEE Transactions on Antennas and Propagation. The case of finite antennas will be investigated as soon as a graduate student can be placed to this project.

2.3. Anisotropic Waveguide - I. Akkaya, Y. T. Lo

The theoretical investigation of a circular waveguide filled with compressible magneto-plasma has been concluded. During this period, some additional computations for the plasma temperature effect on the dispersion relation of the guide have been made. Two papers on this work are being prepared. Miss Akkaya's thesis will be issued as a Scientific Report.

2.4. Theoretical and Experimental Investigation of Circular Waveguides Partially Filled with Warm Plasma - C. Liang, Y. T. Lo

During the last interval, the study of the propagating characteristics of the fundamental modal waves in the guide has almost been completed with particular emphasis on the symmetrical E-type of modal propagation. It is found that its propagating characteristics closely resemble those of the plasma-filled parallel-plate or of the circular waveguides. [Lee, Liang and Lo, and Akkaya] The coupling structure in the optical and acoustic-coupled mode region, as well as the characteristics in the slow-wave mode region, are investigated in detail.

At present, the input impedance of an axially-oriented dipole current source which will excite the symmetrical E-waves in the guide is under investigation. Basic theorems such as the reciprocity relations and the orthogonality conditions for an inhomogeneously-filled compressible plasma guide have been obtained. For comparison, the input impedance of an identical antenna located in a cold plasma waveguide will be obtained. Thus, analytically, one may study the effect of the electron temperature on the antenna impedance.

The 2" complete vacuum station (VEECO, VS-9) was delivered to us in May, and its performance has been satisfactory, achieving an ultimate pressure of 1.5×10^{-6} mm of Hg without using liquid nitrogen cooling. A refilling manifold was built and assembled to the vacuum system. In order to acquire some experiences with gaseous discharge, a simple discharge tube having an "inverse" brush cathode was built. It was found that an electron density of $6 \times 10^{9}/cm^{3}$ and an electron temperature of $2750^{o}k$ may be obtained from a DC helium discharge at a pressure of 360 microns of Hg. Langmuir probes of various configurations and located at different parts of the tube were used.

At present, a discharge chamber scaling down to the size of a regular waveguide is being constructed. A good method is still being searched for producing a reasonably warm steady-state gaseous discharge whose electron temperature can be altered within a suitable range without affecting other plasma parameters.

2.5. Coupling of Modal Waves in a Plasma-filled Parallel-plate Waveguide.

- S. W. Lee, C. Liang, and Y. T. Lo

Previously, we pointed out that a complete consistency in field solutions of two plasma models (compressible and incompressible) could not be obtained at the zero temperature limit. However, the quantitative analysis for the propagating modal waves was not carried out. During this period, this problem was examined in detail. It was found that for the wave frequency below the plasma frequency, the only propagating mode is a slow wave. For frequency above the plasma frequency, two types of propagating modes are possible. The first, which can be called the quasi-optical modes, is identified as that existing in a cold plasma model, but slightly modified due to the compressibility of the plasma. The second, which can be named as the quasi-acoustic modes, is due to the compressibility of the plasma. The second type of modes has a nearly continuous spectrum of propagation constant since the transverse dimensions of the waveguide are a very large number of wavelengths. Approximate solutions have been found which show explicitly the plasma temperature effect on the propagation characteristics.

When the phase velocities of these two types of modes become nearly equal, a strong coupling effect results so as to form a hybrid mode. To our knowledge, this is the first time that an analysis of the $k\beta$-diagram for the electro-acoustic waves has been made.

A paper is being prepared and submitted for possible publication.

2.6. Reflection and Transmission of Electromagnetic Waves by a Moving Uniaxially Anisotropic Medium. - S. W. Lee and Y. T. Lo

One of the problems of fundamental interest in the electromagnetic theory is the reflection and the transmission of waves at the boundary of two media. When both media are stationary with respect to the observer, the solution is simple and can be found in most textbooks. With the advance of the ionospheric and astrophysical studies, the case when these two media have relative motion becomes of some importance.

In this study, the reflection and transmission of electromagnetic waves at the interface between a stationary isotropic medium and a uniaxially anisotropic medium moving parallel to the interface is investigated. Solutions are obtained for the incident E-field parallel (E_{11})or perpendicular ($E_{\perp}$) to the plane of the incidence when the moving medium is either a non-dispersive uniaxial crystal or a dispersive uniaxial plasma. It is found that (i) total reflection is possible even if the wave is incident from a comparatively less "dense" medium into a "dense" medium; (ii) Brewster angles may exist even for an incident $E_{\perp}$ field; (iii) backward wave may be excited in the moving uniaxial plasma by an incident E_{11} field. Other interesting features which are not found in the case of two stationary media are also discussed in detail.

Results of this investigation are to appear in the Journal of Applied Physics.

2.7. Transient Radiation of a Uniaxially Anisotropic Plasma.

- S. W. Lee and R. Mittra

In recent years, there has been much interest in the study of radiation and impedance properties of antennas in anisotropic media. Though the principal motivation has been the prediction of the performance of antennas mounted on space vehicles, the analytical problems have been found interesting in their own right. This is because the theoretical studies have predicted some anomalies or paradoxes in the impedance and radiation characteristics of sources in such media. Several theories have been advanced to explain the causes for such anomalies and the subject has stirred up much controversy among the workers in the field. One of the principal issues under discussion is the so-called 'Infinity Catastrophe', referring to the behavior of the input impedance of small antennas in an overdense plasma. The analysis of these antennas show that for such a medium, the fields produced by short dipoles may become infinite along certain characteristic cones and that the impedance of a short antenna is inversely proportional to its length. Means for resolving the paradoxical situation have also been suggested by a number of workers. However, as yet there is no evidence that a completely satisfactory resolution of the problem has been achieved.

This study attempts to gain further insight into the problem by investigating the transient behavior of the fields excited by infinitesimal sources in a uniaxial anisotropic medium. The propagation of the wave front is calculated along different angular directions as functions of radial distance and time. It is found that, as a consequence of the anisotropy of the medium, the geometry of the wave front may deviate considerably from a spherical surface. For $X = (\omega_p/\omega_o) < 1$, the signal travels further along the

magnetic axis than in the direction transverse to this axis. A much more pronounced effect occurs for $X > 1$, as the wave front becomes four-leafed. These correspond to non-overlapping regions where the signal is either strictly propagating or strictly evanescent. For a given time, there is also a dark region separating these two where no signal has reached. Of particular interest is the result that the critical characteristic bi-cones where the fields become infinite in the steady-state analysis always remain in the dark region. This dark region narrows to zero only in a limit of $t \to \infty$. These results shed new light on the so-called 'infinity catastrophe' problem which has become a subject of much controversy in recent years. The results of the present study suggest the desirability of a more realistic model for the medium which will include finite losses.

A paper based on this investigation is to be presented in the USNC/URSI Fall Meeting in December 1966, Stanford, California.

2.8. Impedance of Antennas in Compressible Plasma.

- J. Carlin, R. Mittra

The impedance properties of biconical and cylindrical dipoles when immersed in a warm plasma have been investigated. The plasma wave was found to have a quite significant effect on impedance when the acoustical phase length ($k_p \ell$) of the antenna was approximately 50 or less. Here

$$k_p = (c/u)\, k_e \quad , \quad k_e = \omega(\mu_o \epsilon)^{\frac{1}{2}}$$

$$\epsilon = \epsilon_o(1-X) \quad , \quad X = \omega_p^2/\omega^2$$

where k_p and k_e are the propagation constants for EM and acoustic waves respectively. ω is the radian operating frequency of the antenna, ω_p - plasma

frequency, ϵ is the permitivity of the plasma and ϵ_o and u_o the permitivity and permeability of free space.

If $\omega > \omega_p$, the impedance was found to have a significantly large real part if $.5 \leq k_p \ell \leq 50$ where ℓ is the half-length of the antenna. This is due to the excitation of acoustic power by the antenna. For wide angle biconical dipoles, an increase in the size of the ion sheath about the antenna decreased the real part of the impedance. The effects of the induced acoustic sources were also investigated for the cylindrical dipole. Previous works have neglected this effect. The acoustic sources were found to have a negligible effect on impedance for the particular case investigated.

A communication on this subject has been published in Electronic Letters and a technical paper has been prepared and has been submitted for publication to the Canadian Journal of Physics.

2.9. Measurement of Antenna Impedance in a Cold Magneto Plasma.

- R. Mittra, D. Snyder

As previously reported, the brush cathode plasma chamber has been used to study the impedance of a small loop antenna immersed in an anisotropic plasma (G. L. Duff). This study has been completed. It seems appropriate to use this equipment for further study of antennas in plasmas in particular to investigate the importance of the antenna orientation with respect to the magnetic field. The antenna chosen was the small (in terms of wavelengths) dipole, since the theoretical behavior of this antenna has already been developed in detail (K. Balmain). The present series of experiments proposes to measure the input impedance of the dipole as a function of plasma parameters and as a function of dipole orientation with respect to the applied magnetic field. It should be noted that previous measurements by Balmain

were done for the transient case alone and for the dipole orientation parallel to the d.c. magnetic field.

To date, the following work has been done:

1. The plasma chamber was disassembled and all contaminants were removed from the glass and electrodes.
2. The vacuum system was overhauled, including disassembly and cleaning of the oil diffusion pump.
3. A new Langmuir probe was constructed and placed in the chamber.

At present, a preliminary study is being conducted using the new Langmuir probe in an attempt to improve the precision of plasma parameter measurements. Subsequently, the dipole will be designed and constructed and free space impedance measurements taken. When construction and measurement techniques have been refined enough so that theoretical and measured free space impedances agree within reason, the antenna will be placed in the chamber for measurements in the plasma environment.

3. PUBLICATIONS UNDER GRANT NSG 395 DURING THIS PERIOD

S. W. Lee, C. Liang and Y. T. Lo

Wave Propagation on Plasma with Very Strong Magnetic Field, Radio Science, Vol. 1 (New Series) July 1966.

J. Carlin and R. Mittra

Terminal Admittance of a Thin Biconical Antenna in an Isotropic Compressible Plasma, Electronic Letters, Vol. 2, No. 6, June 1966.

Papers presented at the Spring URSI meeting (Washington, D.C.)

S. W. Lee and Y. T. Lo

Current Distribution and Input Impedance of an Infinite Cylindrical

Antenna in Anisotropic Plasma.

G. A. Deschamps and O. B. Kesler

Radiation of an Antenna in a Compressible Magnetoplasma.

4. TRAVEL

Professor G. Deschamps attended and participated in the XV General Assembly of the Union Radio Scientifique Internationale (URSI). The meeting was held in Munich, Germany during the first two weeks of September. Professor Deschamps presented a communication on the radiation of an antenna in a compressible magneto plasma and contributed to the reporting of the sessions of Commission VI on ionized media.

These sessions were very well attended, not only by members of Commission VI, but also members of other Commissions. This confirms the practical importance of the problems discussed for the probing of the ionosphere and in some instances for Radio Astronomy and Communication.

5. FINANCIAL INFORMATION

Financial information is contained in the Quarterly Financial Reports submitted by the University of Illinois Business Office on Form No. 1030.